Influence of Dust Composition on Cloud Droplet Formation

James T. Kelly
Lawrence Livermore National Laboratory
Climate & Carbon Science Group

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Activation of Freshly-Emitted Dust

- **Dust is often modeled as insoluble at emission**
- **Can insoluble dust activate?**
  - **Modeling studies:** Insoluble dust cannot activate
  - **Laboratory studies:**
    - Multilayer water coverage for RH < 100%
    - Activation of $CaCO_3$ at high supersaturation

Activation of Transported Dust

- **Atmospheric aging of dust**
  - $CaCO_3 + SO_2 \rightarrow \mathbf{CaSO_3} + CO_2 \xrightarrow{O_3} \mathbf{CaSO_4} + CO_2$
  - $CaCO_3 + H_2SO_4 \rightarrow \mathbf{CaSO_4} + H_2O$
  - $CaCO_3 + 2HNO_3 \rightarrow \mathbf{Ca(NO_3)_2} + CO_2 + H_2O$
  - Dust $+ 2NH_3 + H_2SO_4 \rightarrow$ Dust $+ \mathbf{(NH_4)_2SO_4}$
- **Other components of transported dust**
  - Mg^{2+}: $Mg(NO_3)_2$, $MgSO_4$, $MgCO_3$
  - K^+ : KNO_3, K_2SO_4, K_2CO_3

Water Competition Involving Dust

- **Dust particles: large & few**
- **Dust CCN deplete water vapor**
- **Can reduced saturation by dust inhibit activation of background aerosol?**
  - Ghan et al. (1998): Water competition involving sea salt can be significant

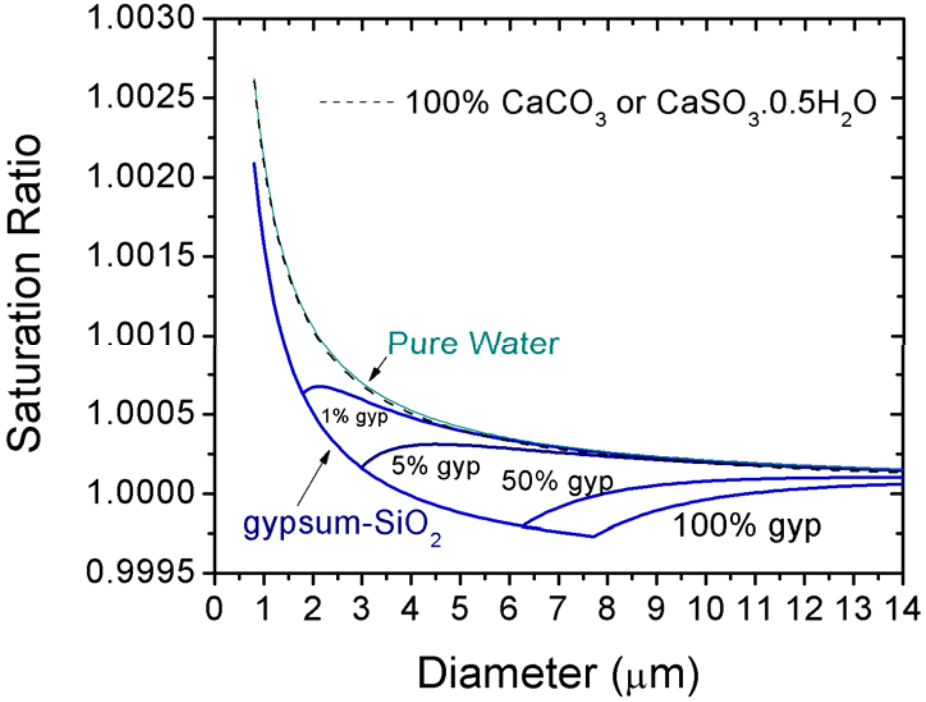
Topics

1. **Influence of minor components of dust on activation**
   - **Approach:** Kohler curves for Ca^{2+}, Mg^{2+}, & K^{+} nitrates, sulfates, sulfites, & carbonates

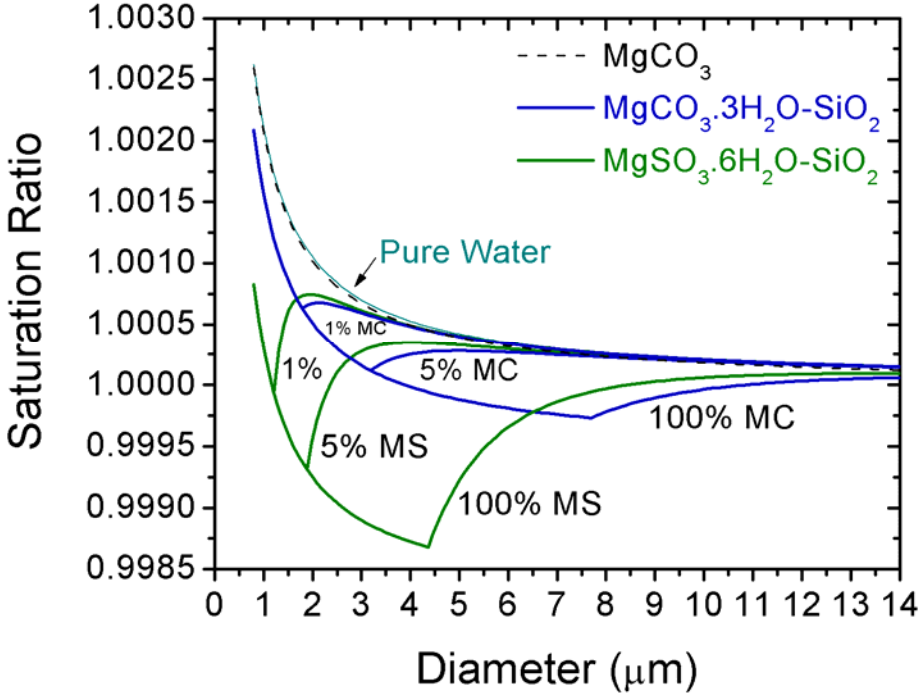
2. **Influence of dust on clouds via water competition**
   - **Approach:** Parcel simulations for dust distribution externally mixed with background aerosol

Kohler Curves: Slightly Soluble Compounds

Ca^{2+} Compounds

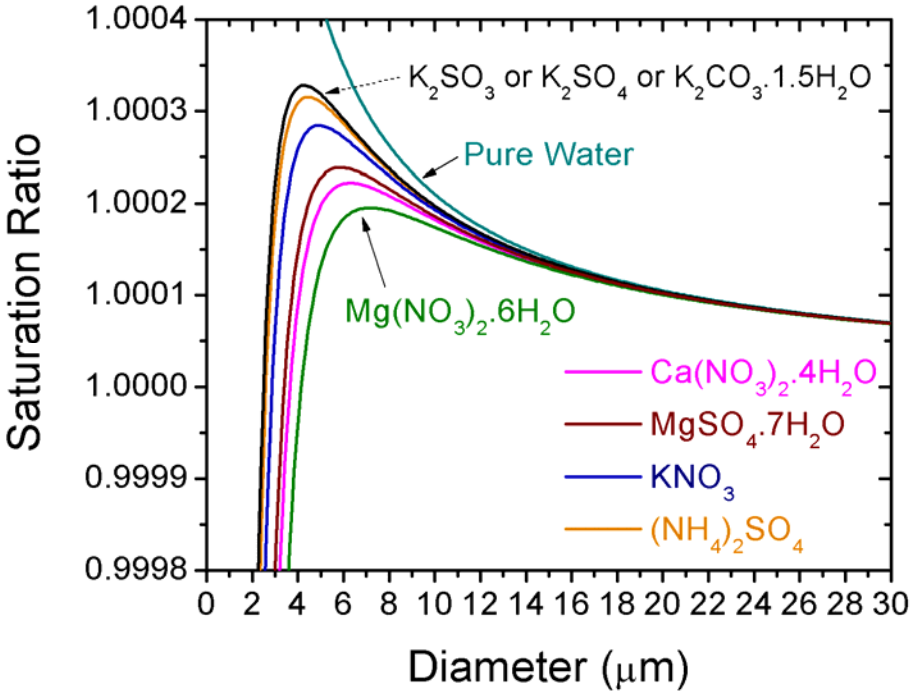


Mg^{2+} Compounds

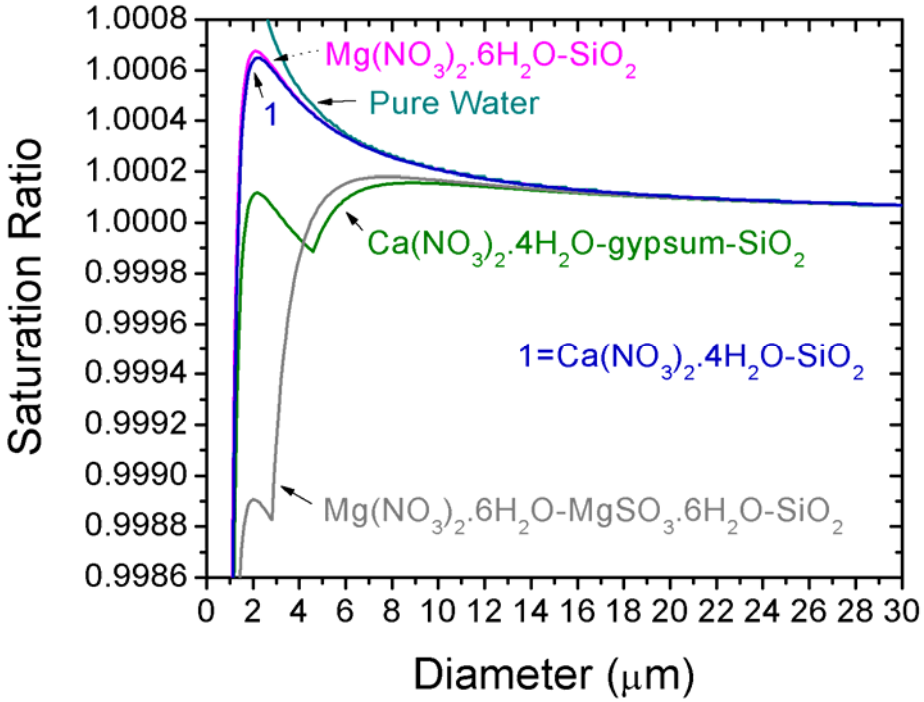


Kohler Curves: Highly Soluble Compounds

Highly Soluble Coating



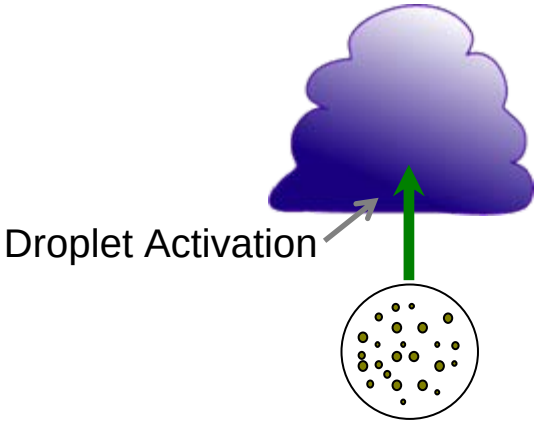
Highly + Slightly Soluble



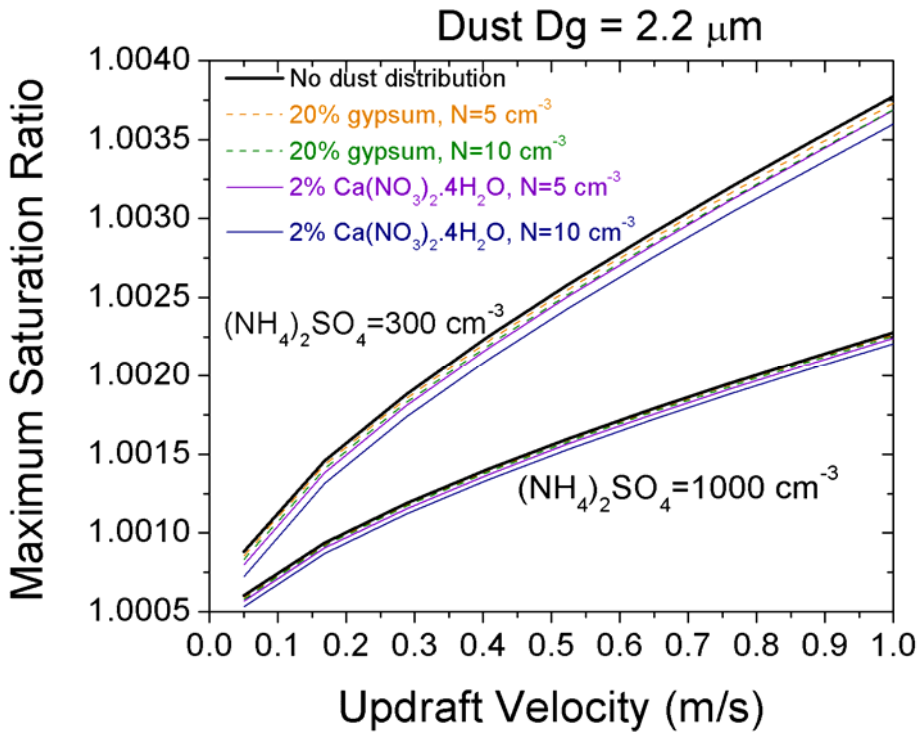
Water Competition: Cloud Microphysics Model

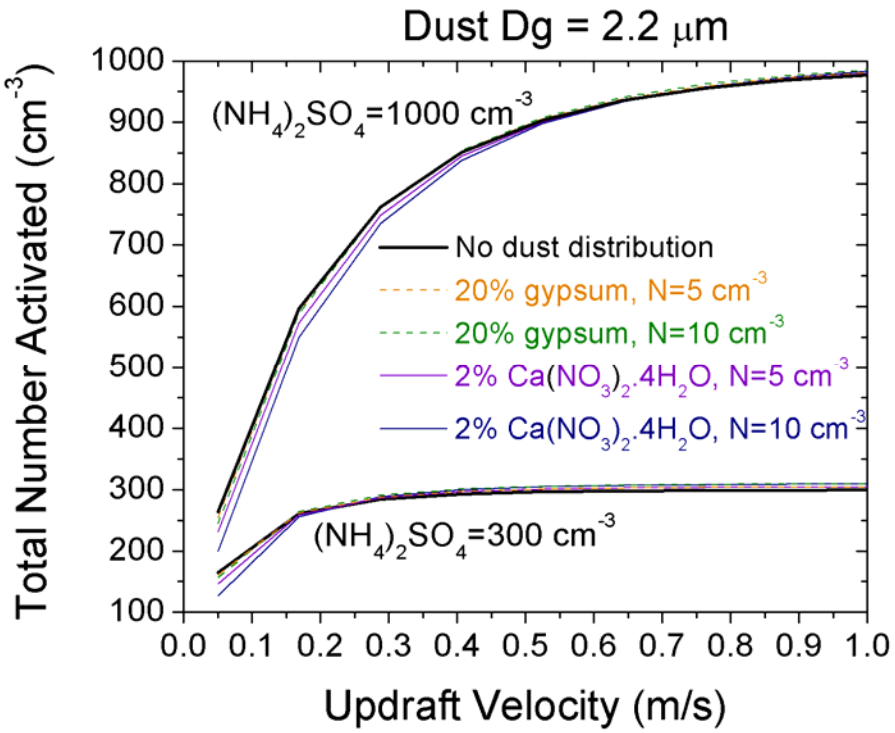
Cloud Parcel Simulations:

- Condensation in rising parcel
- $(NH_4)_2SO_4$ aerosol (D_g=0.16 μm, σ_g=1.4) externally mixed w/ dust
- Does dust influence **maximum saturation** and **cloud droplet number**?



Water Competition: Single-Mode Dust





Conclusions

- **Influence of dust composition is function of size**
  - **For ~0.2% supersaturation**
    - **Dust > 1 μm:** activates **regardless of composition**
    - **Dust 0.6–1 μm:** activates w/ **slightly soluble compounds** (e.g., $MgSO_3.6H_2O$, $CaSO_4.2H_2O$)
    - **Dust < 0.6 μm:** activates w/ **highly soluble compounds** (e.g., all K^+ compounds, $Mg(NO_3)_2$, $MgSO_4$, $Ca(NO_3)_2$)
- **Influence of dust on clouds via water competition only under extreme conditions**

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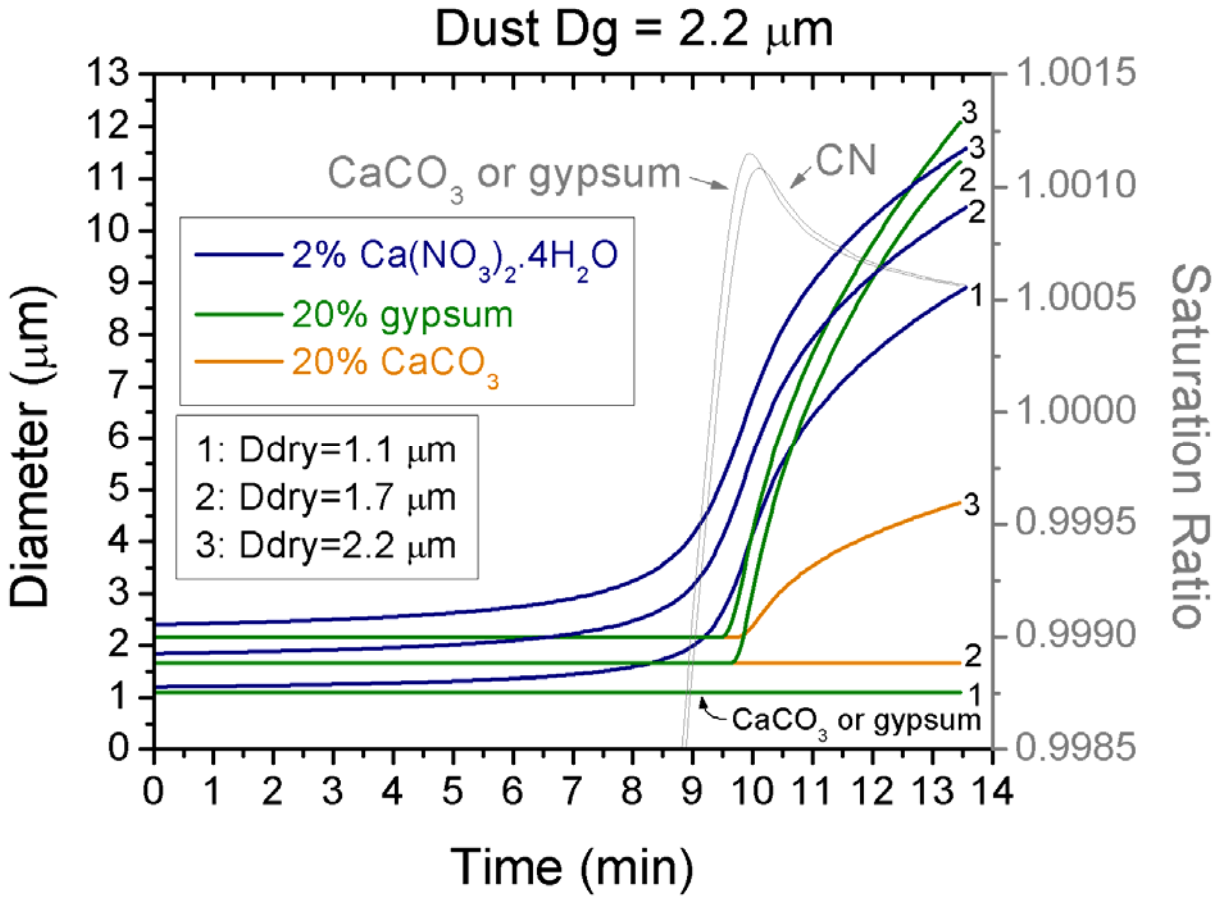
Influence of Composition on Growth

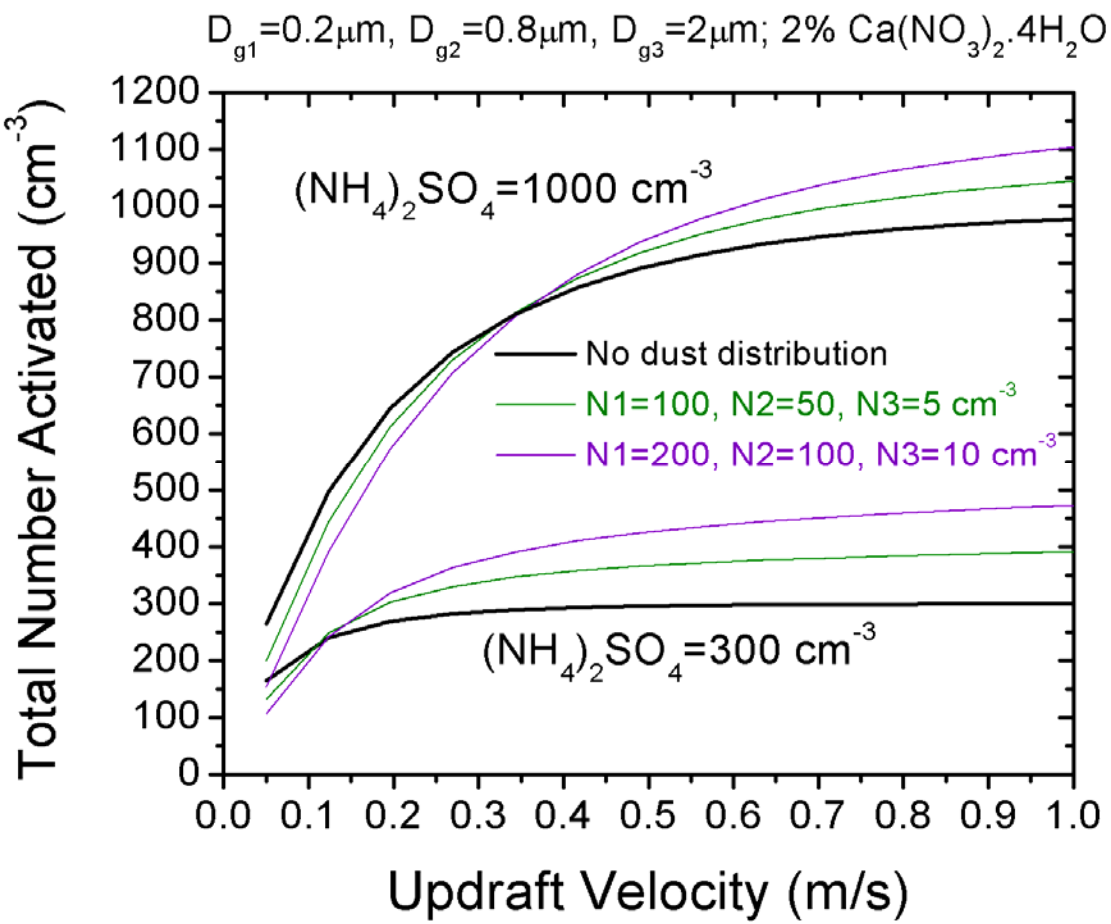


Equilibrium (Kohler) Theory

- **Saturation ratio for curved solution droplet**

$$S_w \approx 1 + \underbrace{\frac{4M_w\sigma_w}{RT\rho_w D}}_{\text{Curvature}} - \underbrace{\frac{6M_w\nu_{HSC}n_{HSC}}{\pi\rho_w(D^3 - D_{core}^3)}}_{\text{Highly Soluble}} - \underbrace{\gamma_{SSC}}_{\text{Slightly Soluble}}$$

Compound	m_{sat}
$Ca(NO_3)_2 \cdot 4H_2O$	8.41
$K_2CO_3 \cdot 1.5H_2O$	8.102
K_2SO_3	6.07
KNO_3	6.07
$Mg(NO_3)_2 \cdot 6H_2O$	4.90
$MgSO_4 \cdot 7H_2O$	3.021
K_2SO_4	0.692

Compound	m_{sat}
$MgSO_3 \cdot 6H_2O$	5.0×10^{-2}
$MgCO_3 \cdot 3H_2O$	1.5×10^{-2}
$CaSO_4 \cdot 2H_2O$	1.5×10^{-2}
$MgCO_3$	8.2×10^{-4}
$CaSO_3 \cdot 0.5H_2O$	7.6×10^{-4}
$CaCO_3$	5.3×10^{-4}

Water Competition: Tri-modal Dust